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Analysis of the aspiration system and gas cleaning for the cooling zone of the sintering machine for phosphorite ore

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Abstract. This study describes the gas emission aspiration and purification system, which is a crucial component of the life support system for a mining and processing plant. The aspiration system aims to maintain favorable working conditions and prevent the increase of dust content and harmful emissions in the air of working areas beyond the maximum permissible values. This study addresses the cleaning of aspiration and gas emissions in the technological zones of sintering machines during the sintering of ore phosphate material. It provides technical solutions for cleaning gases during the sinter cooling process, considering the condensation of moisture from gases inside exhausters. The text also reveals the technological parameters for the functioning of foam apparatuses, cyclones, and splash catchers. The process of cleaning gases in the technological cooling zone of the sintering machine is carried out in two parallel foam apparatus, using both dry and wet methods.

1 Introduction

During the thermal treatment of ore raw materials on the conveyor belt of the sintering machine, toxic gas emissions are produced [1]. Special attention is given to the gases formed during the technological cooling zone of the sintering machine, as well as during the processing of phosphate ore raw materials, sinter, coke, and quartzite [2]. Aspiration systems aim to improve working conditions and prevent dust levels in the air from exceeding maximum permissible concentrations [3-4]. This is done by containing emissions at their source and purifying the air from harmful components. The initial data provided focuses on purifying aspiration air in the raw material preparation shop and sintering department [5].

Based on our analysis of air purification installations in the phosphate industry and experience with similar installations in metallurgical plants, we recommend a two-stage purification process for aspiration air with inlet dustiness over 10 g/m^3. The first stage should be a dust removal chamber, followed by cyclones for the second stage of purification [6]. When the dustiness is less than 10 g/m^3, it is recommended to use cyclones

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for one-stage cleaning of aspiration air. The aspiration gases in the charge preparation and sintering departments are primarily composed of coarse dust particles with an average median diameter of 40-80 microns.

This allows for the use of dust removal chambers as the first stage of purification without incurring additional energy costs, with an efficiency of 40-50% [7].

2 Materials and methods

The gas emissions parameters during the ore phosphate raw material sinter cooling process at the inlet to the purification system are as follows: gas volume – 500K m3/h, temperature - 350 ºC, and rarefaction – 4-5 kPa. The following are the concentrations of toxic components in g/nm3: dust - 3.0, sulphur dioxide - 0.16, sulphur trioxide - 0.02, total fluorine - 0.025 (including silica fluoride - 0.01), phosphorus pentoxide - 0.03, and sodium chloride - 0.25.

The parameters of gases at the inlet to the gas cleaning from one furnace are: volume – 100K m^3/h, temperature - 40-60ºC, and moisture content - 20 g/m^3. Toxic component content in g/m^3: phosphorus pentoxide - 0.1, total fluorine - 0.13 (including silica fluoride - 0.02), sulphur dioxide - 0.2, and dust - 0.2. The technical solutions for cleaning gases from the sinter cooling process are similar to those used for cleaning gases from the chemical-energy technological process of sintering. The gases from the cooling process first enter the first stage of the purification system, which consists of four single parallel position 1 cyclones, Figure 1. From the hoppers of these cyclones, a portion of the gases is passed by a smoke pump (position 2) through two parallel conical cyclones (position 3). The dust captured in cyclones 1 and 3 is returned to the sintering process. After passing through the dry-cleaning stage, the gases enter the wet cleaning stage, which consists of two parallel foam apparatuses with a foam layer stabilizer at position 4.

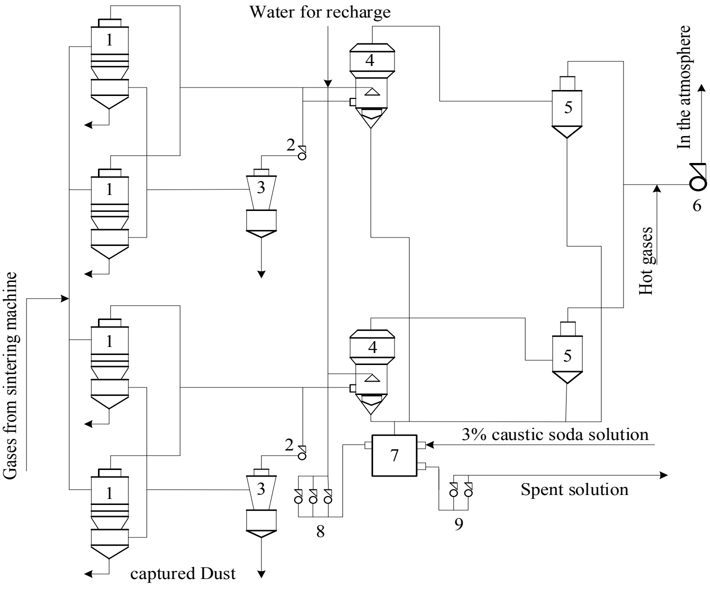

Fig. 1. Gas Purification Scheme for Sinter Cooling Process includes a cyclone (1), smoke pump (2), conical cyclone (3), parallel foam apparatuses with a foam layer stabilizer (4), centrifugal splash catcher (5), exhauster (6), circulation tank (7), circulation pump (8), and slurry pump (9).

The gases that are cleaned in the foam apparatuses are directed to centrifugal-type splash collectors. Once the gases are freed from the splash, they are discharged into the atmosphere through a chimney using an exhauster [8]. To prevent moisture condensation from the gases inside the exhauster, hot gases are introduced into the section of the gas duct located between the splash collectors and the exhauster. The apparatuses are irrigated with a 3% solution of caustic soda, continuously fed into circulation tank 7. Pumps at position 9 remove the spent solution from the bottom of tank 7 and direct it to the evaporation basin. Wet one-stage gas cleaning in foam apparatuses is planned based on gas parameters, physical and technical properties of gas and dust, and experience from similar plants at existing enterprises.

The foam apparatus design differs slightly from the recommended apparatus for cleaning gases in chemical-energy technological processes involving sintering and cooling of sinter [9]. The contact stage consists of a continuous, horizontally located partition with a diameter of 0.9 times the inner diameter of the apparatus body, with a truncated cone mounted on it. This baffle forms an annular gap with the casing wall. This apparatus creates a more developed surface of contact between gas and liquid phases compared to the apparatus recommended for gas cleaning of sintering and sinter cooling processes [10]. However, it has specific disadvantages. Firstly, the gas velocity in the cross-section of the apparatus is lower, resulting in lower specific productivity. Secondly, the maximum diameter of the apparatus should not exceed 3.2-3.5 m. Based on this, these apparatuses can be used to purify gases with a volume of up to 100-120 thousand m^3/h.

The reactions between the toxic components in the gases and the caustic soda solution can be described by the following equations:

$$NaOH + HF \rightarrow NaF + H_2O$$

$$4NaOH + 3SiF_4 \rightarrow 2Na_2SiF_6 + SiO_2 + 2H_2O$$

$$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$$

$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$$

$$4NaOH + P_2O_5 \rightarrow 2Na_2HPO_4 + H_2O$$

To replace evaporated water, continuously feed the calculated amount of water to the upper stage of the foam apparatuses at position 4. The cyclone operation parameters at position 1 are: conditional gas velocity in the cross-section - 4.9 m/s, hydraulic resistance – 3000 Pa, and dust collection efficiency – 82 %. The parameters of cyclone operation at position 3 are: conditional velocity of gases in the cross-section of the apparatus - 1.8 m/s, hydraulic resistance – 3K Pa, and dust collection efficiency - 94%. Foam apparatus operation parameters, position 4: circulating irrigation of 3% caustic soda solution, with an average gas velocity of 2.45 m/s in the free cross-section. Irrigation density is 20 m^3/m^2·h, with a flow rate of circulating irrigation solution of 400-500 m^3/h. The make-up water required for the entire cleaning system is 43-46 m^3/h, while the spent solution from the entire system is 3 m^3/h. Caustic soda consumption for the whole system is 0.86 t/h, with a hydraulic resistance of 5000 Pa. The splash catcher's operation parameters are as follows: gas velocity in the free section is 3 m/s, hydraulic resistance is 1K Pa, and splash capture efficiency is 98%. The toxic component content in the gases at the outlet of the splash catcher (before the hot gases enter the gas duct) is as follows: dust - 0.03 g/m^3, sulphur dioxide - 003 g/m^3, sulphur trioxide - 0.008 g/m^3, total fluorine - 0.008 g/m^3, including silica fluoride - 0.004 g/m^3, phosphorus pentoxide - 0.01 g/m^3, and sodium chloride - 0.06 g/m^3.

The gas parameters at the outlet of the splash catchers (before the hot gases enter the gas duct) are volume - 76.4 m^3/s, temperature - 63-65 ºC, and splash content - 0.1 g/m^3.

The emission of toxic components into the atmosphere is as follows: dust - 0.03 g/m^3, sulphur dioxide - 0.04 g/m^3, sulphur trioxide - 0.009 g/m^3, total fluorine - 0.009 g/m^3, including silica fluoride - 0.004 g/m^3, phosphorus pentoxide - 0.01 g/m^3, and sodium chloride - 0.05 g/m^3.

The parameters of the gases at the inlet to the exhauster, after the hot gases are introduced into the gas duct, are a volume of 84.7 m^3/s and a temperature of 80 ºC. The gas purification efficiency from toxic components is as follows: dust – 99 %, sulphuric dioxide – 75 %, sulphuric trioxide – 55 %, total fluorine – 80 %, including silica fluoride – 60 %, phosphorus pentoxide - 66.6 %, and sodium chloride – 75 %. The solution's component contents are as follows: dust - 70.5 g/l, sodium sulphate - 20.4 g/l, sodium sulphite - 16.5 g/l, sodium fluoride - 1.5 g/l, sodium silicon fluoride - 6.2 g/l, sodium chloride - 22.5 g/l, and sodium phosphite - 6.5 g/l.

Two parallel foam devices are supplied with gases from the slag lanes and chutes of the furnace department, with a flow rate of 100 m^3/h and a temperature of 40-60 ºC. The foamers are irrigated in circulation mode with a caustic soda solution. The sludge pumps continuously discharge the spent solution from the circulation tank, while $NaOH$ solution is continuously fed into the same tank. The purified gases are drawn through a fan and released into the atmosphere. To reduce wastewater and spent solutions, ensure stable operation of gas cleaning equipment with high efficiency, and reduce corrosion [11], the concentration of the caustic soda irrigation absorption solution should be 3%, and the discharged spent solution should have a pH of 7-8. The following are the parameters for operating the foam apparatus for one furnace: irrigation density should be between 15 to 20 $m^3/m^2 \cdot h$, irrigation solution consumption should be 200 m^3/h, water consumption for make-up should be 5 m^3/h, amount of spent solution should be 1 m^3/h, gas velocity in the apparatus cross-section should be 1.73 m/s, apparatus resistance should be 6K Pa, and $NaOH$ consumption should be 0.05 t/h.

The parameters of gases at the apparatus outlet are as follows: volume – 74880 m^3/h, temperature - 30 to 40 ºC, moisture content – 60 g/m^3, and splash content – 5 g/m^3.

The following are the concentrations of toxic components in g/m^3: phosphorus pentoxide - 0.01, total fluorine - 0.01, sulphur dioxide - 0.01, and dust - 0.02. The capture efficiency of toxic components is as follows: phosphorus pentoxide - 90%, total fluorine - 92.3 %, sulphur dioxide – 95 %, and dust – 90 %. The exhaust solution contains the following components in g/l: dust - 14.2, sodium sulphate - 16.4, sodium sulphite - 14.5, sodium fluoride - 14.6, sodium silicofluoride - 12.5, and sodium phosphate - 14.8.

In phosphate production, gases are discharged from various sources including the slag discharge unit, chutes and casting machines of ferrophosphorus discharge, and hatches of electrostatic precipitators [12]. These discharges are typically short in duration. The gases discharged from ferrophosphorus discharge chutes contain the highest concentration of toxic components, as shown in Table 1.

Table 1. Aspiration gases parameters.

	Chutes, and	**Dispensing machines**	**Electric precipitator hatches**
Volume, m^3/h	100000	100000	100000
Temperature, ºC	60÷80	50÷60	40÷50
Moisture content, g/m^3	20	20	20
Toxic content, g/m^3			
Dust	0.2	0.1	0.2
Sulphur dioxide	0.4	0.2	0.1
Sulphur trioxide	0.03	0.02	0.01
Total fluorine	0.35	0.2	0.1
Phosphorus pentaoxide	0.5	0.25	0.4

Foam devices intended for cleaning gases from slag drainage units can also be used for cleaning gases from slag and ferrophosphorus drainage from furnaces. However, the capacity of foam devices is limited to 100K m^3/h, so not all gases can be passed through them. Gas removal from the electrostatic precipitator hatches and ferrophosphorus discharge unit is not carried out simultaneously, while removal from the chutes and ferrophosphorus caster is almost simultaneous [13]. Therefore, it is most expedient to direct the gases discharged from the chutes for purification at the moment of ferrophosphorus discharge, as they contain the largest amount of toxic components [14]. During this period, harmful substances are not released from the slag discharge unit as gas removal is not carried out. After ferrophosphorus discharge, the purification system switches to remove and purify gases from the slag discharge unit. The gases discharged from the caster are released into the atmosphere without treatment.

3 Results and Discussion

The gases from the electric precipitator hatches are also sent to foam devices for purification, as they coincide with the removal of gases from the slag and ferrophosphorus discharge unit. The foam devices operate under similar technological parameters as those used for cleaning the gases from the slag discharge unit [15].

The emission of toxic components into the atmosphere from chutes is measured in grams per normal cubic meter (g/m^3). The following are the maximum allowed levels of toxic components: dust - 0.02 g/m^3, sulphur dioxide - 0.02 g/m^3, total fluorine - 0.027 g/m^3, and phosphorus pentoxide - 0.05 g/m^3.

Similarly, the emission of toxic components at air discharge from electric precipitator hatches is also measured in g/m^3. The maximum allowed levels of toxic components are: dust - 0.02 g/m, sulphur dioxide - 0.005 g/m^3, total fluorine - 0.008 g/m^3, and phosphorus pentoxide - 0.04 g/m^3.

4 Conclusion

Therefore, based on the analysis of air purification plants in existing phosphate industry plants and the operating experience of similar plants in mining and processing facilities, we recommend a two-stage purification process for aspiration air when the inlet dustiness exceeds 10 g/m^3. The first stage should be in the dust removal chamber, followed by the second stage in cyclones. For dust levels below 10 g/m^3, it is recommended to use cyclones for one-stage aspiration air cleaning. The use of two parallel foam apparatus for dry and wet cleaning of gases formed in the technological cooling zone of the sintering machine is scientifically justified. The problem statement discusses the purification of aspiration air in phosphorus production, considering the input dustiness of charge preparation and sintering departments, as well as the average median diameter of suspended particles. This approach enables the use of dust removal chambers in the first stage of purification. The foam apparatus used for aspiration air purification should have a highly developed contact surface between gas and liquid phases. This differs from the apparatus recommended for gas purification in sintering and cooling processes of phosphorite agglomerate. We propose a hardware engineering solution to redistribute gas-air flows in a complex system for aspiration air purification in phosphate production.

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